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AVOIDANCE BASED ON SHOCK INTENSITY REDUCTION WITH NO CHANGE IN SHOCK PROBABILITY

PHILIP J. BERSH[1] AND LAUREN B. ALLOY

TEMPLE UNIVERSITY

Rats were trained on a free-operant avoidance procedure in which shock intensity was controlled by interresponse time. Shocks were random at a density of about 10 shocks per minute. Shock probability was response independent. As long as interresponse times remained less than the limit in effect, any shocks received were at the lower of two intensities (0.75 mA). Whenever interresponse times exceeded the limit, any shocks received were at the higher intensity (1.6 mA). The initial limit of 15 seconds was decreased in 3-second steps to either 6 or 3 seconds. All animals lever pressed to avoid higher intensity shock. As the interresponse time limit was reduced, the response rate during the lower intensity shock and the proportion of brief interresponse times increased. Substantial warmup effects were evident, particularly at the shorter interresponse-time limits. Shock intensity reduction without change in shock probability was effective in the acquisition and maintenance of avoidance responding, as well as in differentiation of interresponse times. This research suggests limitations on the generality of a safety signal interpretation of avoidance conditioning.

Key words: avoidance, shock intensity reduction, response-independent shock probability, interresponse time, differentiation, lever press, rats

An avoidance conditioning procedure, whether of the discriminated or free-operant variety, typically permits the organism to avoid aversive stimulation entirely. Little research is available on the avoidance of higher intensity aversive stimulation under conditions where such avoidance exposes the organism to lower intensity aversive stimulation. Powell and Peck (1969) found that Sidman avoidance was actually more successful when each response merely reduced shock intensity for the response-shock (R-S) interval than when it delayed the shock for that period of time. Campbell (1956) reported that animals exposed to shock of different intensities in two halves of a tilt cage remained on the low-shock half to a degree that depended on the magnitude of intensity difference relative to the absolute intensity of the stronger shock. This constituted passive avoidance of the higher intensity shock. A number of studies also have demonstrated escape conditioning on the basis of a reduction in shock intensity to a value greater than zero (*e.g.*, Bower, Fowler, and Trapold, 1959; Campbell and Kraeling, 1953; Weiss and Laties, 1959, 1963).

The present experiment investigated further the avoidance of higher intensity shock under conditions that exposed animals to lower intensity, though still aversive, shock. Only the shock intensity was contingent on responding; shock occurrence was response independent. In addition, negative reinforcement as a result of avoidance of the higher intensity shock was used to differentiate interesponse times (IRT). Response differentiation through negative reinforcement has not previously been investigated in a systematic fashion. Differentiation of IRTs through positive reinforcement is, of course, readily obtainable with both differential-reinforcement-of-low-rates (DRL) schedules and differential-reinforcement-of-high-rates (DRH) schedules.

In the present experiment, a schedule somewhat analogous to the DRH schedule was employed. It differed from the schedule used by Powell and Peck (1969) in several ways. Their procedure was a modification of the one developed by Sidman (1953), in which shocks occurred every 5 sec regardless of responding and every response reduced shock intensity for a

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20-sec period following the response. Resumption of high intensity shocks occurred as soon as 20 sec elapsed without a response. In the present experiment, shocks were response independent and randomly distributed in time. Only those level-press responses that met an IRT requirement could reduce the intensity of the shocks to a lower level or could prolong exposure to the lower intensity shocks. As long as an animal's responses met the IRT limit, any shocks received were at the lower intensity. Whenever the IRT limit was exceeded, any shocks received were at the higher intensity. However, because the shocks were randomly distributed, higher intensity shocks might not begin as soon as the IRT limit was exceeded. Thus, an animal could still avoid higher intensity shock if it responded twice with an IRT equal to or less than the limit before the next scheduled shock occurred.

METHOD

Subjects

Four experimentally naive, male Sprague-Dawley rats, Holtzman strain, weighing 250 to 300 g at the start of the experiment, were housed individually and given free access to food and water in their home cages.

Apparatus

The experimental chamber (Lehigh Valley Electronics Model 11414) consisted of Plexiglas sidewalls and ceiling, stainless-steel front and rear walls, and a grid floor. The internal dimensions were 30.2 cm long, 24.0 cm wide, and 36.8 cm high. A stainless-steel lever (Lehigh Valley Electronics Model 1352) requiring a force of approximately 0.1 N to depress and measuring 2.7 cm wide and 0.9 cm in thickness, protruded 2.5 cm through the front wall. The lever center was located 3.0 cm above the grid floor, 3.5 cm from the rightmost sidewall. Stainless-steel grid bars, 0.5 cm in diameter mounted perpendicular to the sidewalls and spaced 1.8 cm apart (center to center) provided the shock delivery surface. Shocks of 0.5 sec duration and either 0.75 mA or 1.6 mA intensity measured at the grids were delivered through a shock scrambler (Lehigh Valley Electronics Model 1311SS) in series with a 150 k ohm resistor. The overhead houselight was a 7.5-W lamp (Tung-Sol) in an amber lens (Dialco). White masking noise of 70 dB, delivered through a large speaker to the experimental room, was constantly present throughout each experimental session. Programming and recording equipment was located in an adjacent room. Interresponse times were recorded in 11 separate bins, with 1 sec as the smallest interval available.

Procedure

Shocks occurred at random intervals throughout the session, with an average density of approximately 10 shocks per minute. At the start of the sessions, shocks were of 1.6-mA intensity (high shock). For Subjects M-1 and M-3, the houselight was on during high shock periods. A response terminated the houselight and introduced a 15-sec period when shocks of 0.75-mA intensity (low shock) might occur. Each subsequent response that occurred 15 sec or less after the previous response reset the timer and extended the period of low-shock exposure. Thus, as long as the pause between responses (IRT) did not exceed 15 sec, the low-shock period continued. Whenever 15 sec elapsed without a response, the houselight came on and any shocks received by the animal were at the higher intensity until the next response was made. If that response preceded the next scheduled shock, the latter was at the lower intensity. This procedure was used for the first 10 sessions. From Session 11 on, the houselight was eliminated, and each high-shock period continued until the animal responded twice with an IRT no greater than 15 sec. As before, low-shock periods lasted at least 15 sec and continued as long as the pause between responses did not exceed the 15-sec limit. After extended training at the 15-sec limit, the animals were shifted to limiting IRT values of 12, 9, 6, and 3 sec in succession. In each case, the shift was made when there appeared to be no further improvement in performance at the previous IRT limit. For Animal M-1, shifts followed five sessions in which the per cent avoidance of high shock during the last hour varied from the five-session mean by less than 1%; for Animal M-3, variation from the five-session mean was less than 2%.

The other two subjects, Rats P-1 and P-2, were exposed throughout to the procedure used from the eleventh session on for Rats M-1 and M-3. That is, the houselight was not used, and two responses with an IRT no

Table 1

Number of Sessions for Each Rat at Each IRT Limit

Subject	IRT Limit 15 sec	12 sec	9 sec	6 sec	3 sec
M-1	95	21	19	49	27
M-3	95	21	19	49	19
P-1	87	15	6	6	—
P-2	85	15	7	6	—

greater than 15 sec were required to terminate high-shock periods. After prolonged exposure to the 15-sec IRT limit, P-1 and P-2 were shifted to limits of 12, 9, and 6 sec in succession. In each case, the shift occurred following five sessions in which the per cent avoidance of high shock during the last hour varied from the five-session mean by less than 3%. There were five daily sessions per week, each lasting 100 min. Table 1 presents the number of sessions at each IRT limit for each animal. The small number of sessions for P-1 and P-2 at the 9-sec and 6-sec limits was necessitated by a laboratory shutdown for the summer months.

Several features of the procedure should be emphasized. (a) Each animal received all shocks, approximately 1000 per session. Only the shock intensity was contingent on the animal's behavior. (b) Failure to meet the IRT requirement did not inevitably result in exposure to high shock. An animal might emit a pair of responses that met the IRT requirement before the next scheduled shock had occurred, thus terminating the period without the occurrence of a high shock. Similarly, a low-shock period need not involve the occurrence of a low shock, since the IRT limit might be exceeded before the next scheduled shock had occurred. The likelihood of such periods increased as the IRT limit was reduced. Obviously, however, continued failure to meet the IRT requirement increased the frequency of high shocks received, while continued responding within the IRT limit increased the frequency of low shocks received.

RESULTS

All results are presented in the form of means for each animal for the last five sessions at each IRT limit. Response rates during low-shock periods for each 10-min interval of a session are graphed in Figure 1. All animals manifested warmup effects, with some tend-

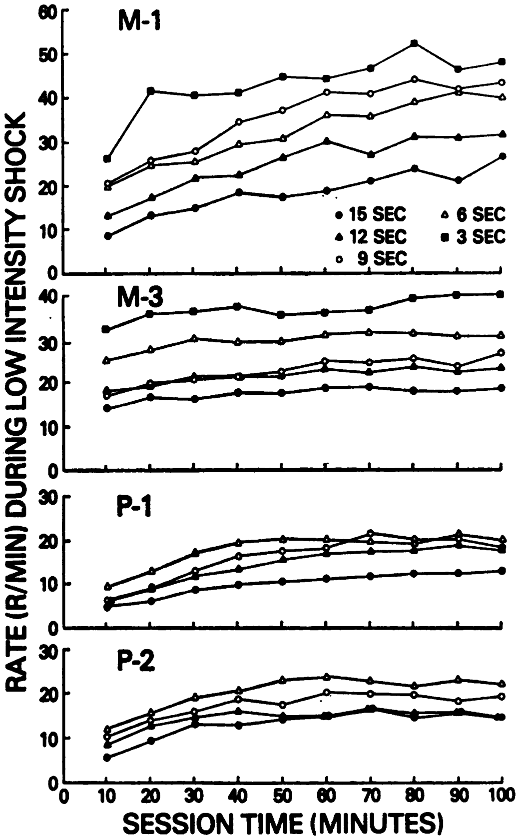

Fig. 1. Response rate per minute during low intensity (0.75 mA) shock periods for successive 10-min intervals of the session at each IRT limit. Each point is a mean based on the rates for the last five sessions at each IRT limit.

ency for the magnitude and duration of the warmup to increase as the IRT limit decreased. For three subjects, Rats M-1, P-1, and P-2, the warmup continued at least for the first half of the session and, in some cases, throughout the session. The systematic increases in rate shown in Figure 1 were present during all of the terminal sessions on which the five-day means are based. By comparison, the warmup for M-3 was less reliable and response rates tended to stabilize after 20 to 30 min. At each IRT limit for this subject there was some overlap between the individual session rates during the first interval and those for almost all of the remaining intervals.

As the IRT limit was reduced, the rate for all animals tended to increase throughout the session. These changes are summarized in Figure 2, which shows the mean rates during low-shock periods for the last hour of the session,

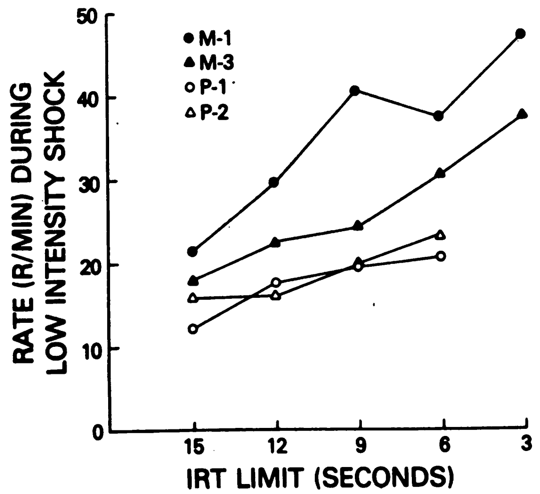

Fig. 2. Response rate per minute during low intensity (0.75 mA) shock periods for the last hour of the session as a function of the IRT limit. Each point is a mean based on the rates for the last five sessions at each IRT limit.

thus eliminating most of the warmup effect. On this and other graphs in which the abscissa represents the IRT limit, the values are arranged from largest to smallest, because this was the order in which animals were exposed to these limits and because the response requirement for avoidance became increasingly severe as the limit was reduced. Figure 2 shows that in the case of Rats M-1 and M-3, rates more than doubled from the 15-sec to the 3-sec limit. Smaller though substantial increases were found for Rats P-1 and P-2, with the 6-sec rate 68% higher than the 15-sec rate for P-1 and 48% higher for P-2. The tendency shown in Figure 2 for response rates to increase as the IRT limit was decreased was also reflected in performances during the individual sessions that entered into the five-session means. For example, in no subject was there overlap between the ranges of the averaged values when the longest and shortest IRT limits for each subject were compared. Although there were varying degrees of overlap involving the intermediate conditions, the overall trend for individual sessions was an increasing one. While not graphed, mean rates for the entire session, though lower, essentially paralleled those for the last hour.

Figure 3 shows the mean number of low intensity shocks received by each animal as a percentage of total shocks received for each 10-min interval of the sessions. Since animals

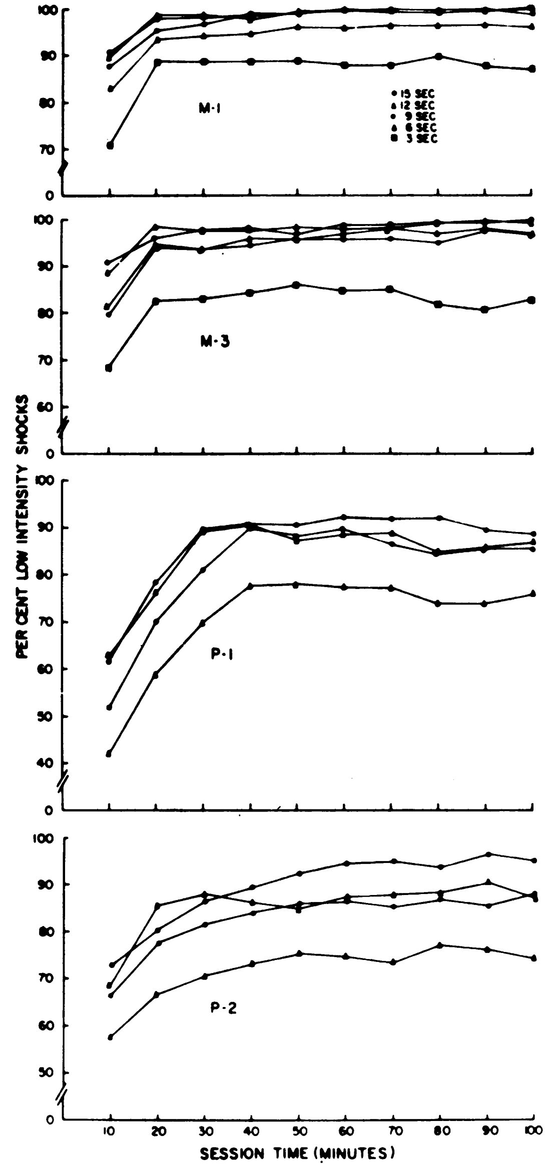

Fig. 3. Number of low intensity (0.75 mA) shocks as a percentage of the total number of shocks received during successive 10-min intervals of the session at each IRT limit. Each point is a mean based on the percentages for the last five sessions at each IRT limit.

received all scheduled shocks, this percentage also represents the percentage of potential high intensity shocks avoided and serves as an index of avoidance performance. Pronounced warmup effects are evident. Mean per cent avoidance tended to stabilize for both M-1 and M-3 after the first 10-min, but continued to increase for P-1 and P-2 at least through the first 30 to 50 min of the session.

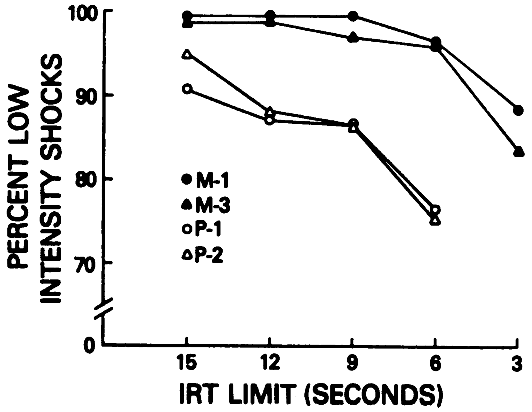

Fig. 4. Number of low intensity (0.75 mA) shocks as a percentage of the total number of shocks received during the last hour of the session as a function of the IRT limit. Each point is a mean based on the percentages for the last five sessions at each IRT limit.

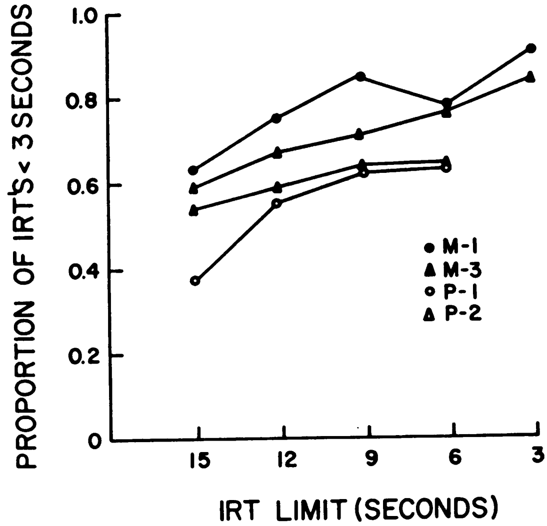

Fig. 5. Proportion of IRTs shorter than 3 sec as a function of the IRT limit. Each point is a mean based on the proportions for the last five sessions at each limit.

For all animals at each IRT limit, there was no overlap of the range of values entering into the five-session means graphed in Figure 3 for the first interval, as compared to intervals three to 10. Reduction in the IRT limit tended to accentuate these trends. Figure 4 shows the mean percentage for the last hour of the sessions. It is clear that performance was maintained by M-1 and M-3 at very high levels of efficiency despite the reduction in the IRT limit from 15 to 6 sec, with the mean percentage of high shock avoidance ranging from 96 to virtually 100. Even at the 3-sec limit, M-1 avoided 88% and M-3 83% of potential high shocks. The detrimental effect of the smallest IRT limit on avoidance performance is supported by the fact that the range of values at the 3-sec limit did not overlap with those at the longer limits. The performances of P-1 and P-2 were not quite as good, decreasing from 91% to 87% for P-1 and from 95% to 86% for P-2 as the IRT limit was reduced from 15 to 9 sec. At the 6-sec limit, both animals avoided about three-quarters of the high shocks and the range of values at this, the shortest limit studied with these subjects, did not overlap with those at the longer limits. As with response rates, values for the entire session paralleled those for the last hour.

Additional evidence for the differentiation of IRTs is found in Figure 5, which presents the mean proportion of IRTs shorter than 3 sec at each IRT limit. These data are provided only for the entire session, because no provision had been made for a temporal breakdown during the session. Since mean rates for the session were parallel to those for the last hour, it is likely that the mean proportions in the figure are reasonably representative of the mean proportions for the last hour. It can be seen that the proportion of brief IRTs tended to increase progressively with the reduction in the IRT limit. Except in the case of P-2, there is no overlap between the ranges at the longest and shortest IRT limits. The proportion increased 0.27 for both M-1 and M-3 as the limit was reduced from 15 to 3 sec. For P-1, the proportion increased 0.26 and for P-2, 0.10 with a decrease in the limit from 15 to 6 sec. All but one of the IRT distributions, based on the mean values for the last five sessions at each limit, had a peak frequency at the smallest measured interval and a progressive decline in frequency as the IRT became longer. The decline from the peak frequency was especially marked for M-1 and M-3. The character of the IRT distributions is illustrated in Figure 6, which presents the set for M-1.

DISCUSSION

Despite the absence of any contingency between behavior and shock occurrence, lever pressing was efficiently acquired and main-

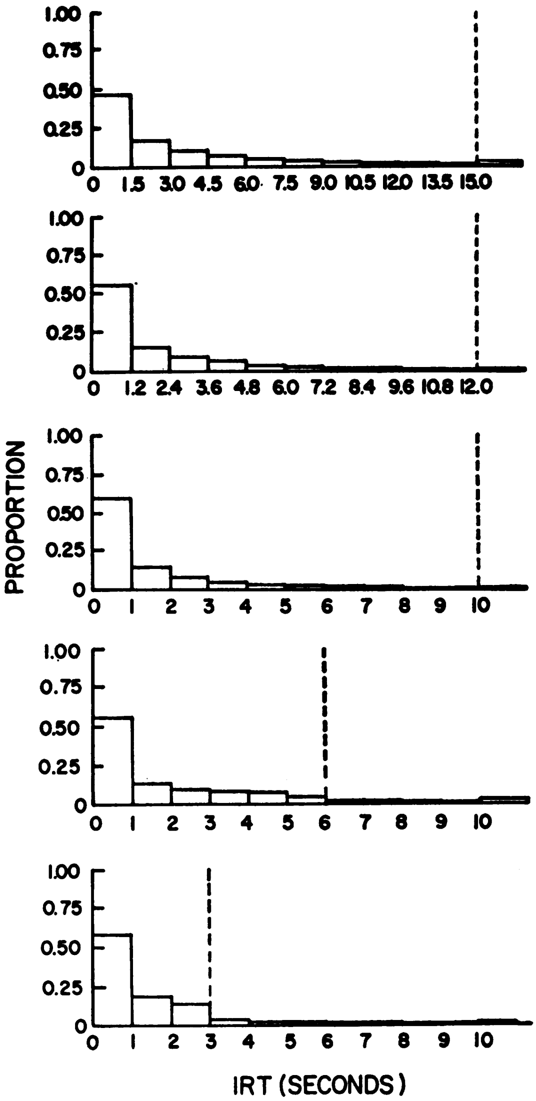

Fig. 6. Interresponse-time distribution for Subject M-1 at each IRT limit. The dashed vertical line marks the IRT limit. Each rectangle is based on the values for the last five sessions at each IRT limit.

tained when it resulted in avoidance of higher intensity shock. In fact, during the last hour of the session, M-1 and M-3 avoided more than 95% of potential high shocks at all but the most restrictive IRT limit (3 sec). While P-1 and P-2 were somewhat less effective, their performance was efficient enough to avoid at least 86% of high shocks during the last hour of the sessions at all but the 6-sec IRT limit. Avoidance conditioning for M-1 and M-3 was aided at the outset by requiring only a single response to shift from a high- to a low-shock period and by use of the houselight as a cue for high-shock periods. Whether these initial conditions or individual differences account for their superior performance cannot be determined. It is also possible that a larger number of sessions for P-1 and P-2 at the 9-sec and 6-sec limits might have improved their avoidance performance somewhat.

These results extend the findings of Powell and Peck (1969) on the effectiveness of shock intensity reduction as negative reinforcement. Thus, noncontingent shock in the present experiment was random instead of periodic as in their study, and failure to meet the response requirement for avoidance of high shock did not automatically produce high shock. Furthermore, only responses that did not exceed an IRT limit could lead to intensity reduction; in their study, each response was effective. The procedure used here succeeded with a shock intensity reduction of 53%. By comparison, initial reduction of 50% was insufficient for avoidance in the Powell and Peck study, and only after training with a 75% intensity reduction was performance successfully maintained on the basis of a 50% reduction. Perhaps this difference was due to the fact that low shock in the present experiment was 0.75 mA *versus* 1.0 mA in their study. These findings suggest that the intensity to which shock is reduced is an important factor in negative reinforcement through shock intensity reduction, in addition to the role played by the relative and absolute size of the reduction. Nevertheless, 0.75 mA, though less aversive than 1.0 mA, is sufficiently aversive in its own right to foster and maintain avoidance behavior (*e.g.*, Bersh and Lambert, 1975). In addition to the smaller percentage reduction, other conditions of the present experiment were more stringent than those employed by Powell and Peck. Thus, a response that met the IRT requirement ensured at best 15 sec of high-shock avoidance *versus* 20 sec for the Sidman-type procedure of the Powell and Peck study, and at worst only 3 to 6 sec of high-shock avoidance.

In their study, Powell and Peck found that shock intensity reduction was superior to complete avoidance and that, once acquired with an intensity reduction procedure, responding was maintained by noncontingent shocks without intensity reduction. These results were attributed to the elicitative and discriminative functions of the shocks. In the present experiment, many responses followed low shocks immediately because intershock intervals averaged 6 sec. Both elicitative and discriminative control by these shocks may have been involved. However, an elicitative role for the low shocks is contraindicated by the fact that despite some decrease in the number of low shocks received as the IRT limit was reduced, the response rate increased. Bersh and Lambert (1975) reported that, at least at the intensity of the low shocks, the role of elicitation in generating responses is exaggerated. They found that rats often made fewer than one lever-press response per 10 shocks in the presence of an S^{Δ} during which shock density averaged one per 6 sec. It is suggested that low intensity shocks served primarily as discriminative stimuli and thus helped to maintain responding during low-shock periods. In the case of M-1 and M-3, particularly at IRT limits of 6-sec or longer, such responding continued for most of the session in the absence of any exposure to high shock. For example, the total duration of high-shock periods for M-1 at interresponse-time limits from 15 to 9 sec often involved less than 2% of the session, with most of this occurring in the first 10 min.

The results showed that the IRT can be differentiated by negative reinforcement based on avoidance of higher intensity shock in favor of lower intensity shock. As the IRT limit was reduced, the proportion of short IRTs during low-shock periods increased progressively. Of course, the response rate during such periods also increased. The possibility that this rate increased was the result of a "spill-over" of responses elicited by high shocks may be ruled out, since the increase often occurred despite little or no change in the frequency of high shocks or in the face of a very small number of high shocks. For example, the mean rate for M-1 during the last hour of a session almost doubled from the 15-sec to the 9-sec IRT limit, but the mean number of high shocks remained constant at about 3.5, only one shock every 17 min. Similarly, the mean rate for M-3 during the last hour of a session increased by 12.4 responses per minute from the 15-sec to the 6-sec limit, but the mean high-shock frequency increased by only one shock every 3.5 min. Furthermore, for all animals, the response rate at a given IRT limit showed a strong tendency to vary inversely with high-shock frequency.

Conclusive evidence against a shock elicitation basis for the present findings was obtained in ongoing research. Animals yoked to rats exposed to the procedure of the present experiment with the 15-sec IRT limit in effect essentially stopped responding. The mean number of responses for 12 yoked animals for the last five sessions was 12.7, while that for their avoidance partners was 865.3. It is also worth pointing out that low shocks, though they may have performed a discriminative function, are not responsible for the rate increase with a reduction in the IRT limit, since, as indicated earlier, low-shock frequency tended to decrease with the IRT limit.

Dinsmoor (1977) maintained that the feedback from an avoidance response constitutes a safety signal, and that such a signal contributes to the maintenance of the response both in discriminated and unsignalled avoidance procedures. Moreover, he suggested that the conditioned aversive temporal stimulus approach of Anger (1963), as applied to free-operant avoidance, can be translated as the fading of the feedback safety signal with time since the avoidance response and the restoration of the signal to full strength by the occurrence of that response. This interpretation is readily extended to the intensity reduction experiments of Powell and Peck (1969). Dinsmoor (1977) also asserted that the safety signal concept is a more appropriate basis than shock frequency reduction for interpreting the effectiveness of the avoidance procedure introduced by Herrnstein and Hineline (1966). The evidence of the present experiment, however, casts doubt on the generality of a pure safety signal interpretation of avoidance conditioning. In view of the IRT requirement for reinforcement, no single response guaranteed the termination of a high-shock period or prolongation of a low-shock period. Once a high-shock period began, it continued as long as the pause between responses exceeded the IRT limit in effect. In addition, a low-shock period terminated whenever the IRT limit was exceeded, so that a single response after the limit had elapsed was ineffective in avoiding high shock. It is clear that the feedback from a lever press could not serve as a cue for either high or for low shock and, therefore, could not by itself function as a safety signal. At a minimum, it seems necessary to assume that the passage of time from the *preceding* response or some process correlated with that passage of time must be added to feedback from the *current* response as the critical basis for the discrimination between effective and ineffective current responses. In other words, aside from the possible discriminative role of low shocks, the IRT itself provided the only unambiguous discriminative basis for effective avoidance responding. As noted earlier, in the present experiment low shocks cannot account for the increase in response rate with reduction in the IRT limit. Perhaps time since the previous response acts as a cue to impart safety signal properties to the feedback from the current response. In the terms of Anger's (1963) approach, there may indeed be an increase in aversiveness with the passage of time since the previous response. Unlike Sidman avoidance, however, where each response decreased this aversiveness, time since the previous response is the key to any drop in aversiveness engendered by the current response. In his discussion of avoidance conditioning, Mackintosh (1974) emphasized the short-term consequences of a response in the maintenance of avoidance behavior. Again, however, the present experiment makes clear that the discriminative basis for such short-term consequences need not be limited to the feedback from any single response.

As indicated earlier, the negative reinforcement schedule of the present experiment was not fully equivalent to a DRH schedule with positive reinforcement. In DRH, failure to meet the IRT requirement always leads to nonreinforcement. However, such a failure in the present experiment did not inevitably produce immediate high shocks. Instead, an animal still might avoid high shocks by responding twice with an appropriate IRT before the next scheduled high shock occurred. The authors were unable to find published graphs of IRT distributions resulting from the DRH schedule with positive reinforcement. Nevertheless, the IRT distributions generated by the schedule used here seem to have the characteristics of distributions to be anticipated under DRH with positive reinforcement. Sidman (1966) reported IRT distributions similar to those of the present experiment with his free-operant avoidance schedule. This is understandable, since the free-operant schedule developed by Sidman is itself somewhat analogous to the DRH schedule, in view of the limit placed on the IRT by the R-S interval. The present data suggest that response differentiation by negative reinforcement may be quite comparable to differentiation by positive reinforcement. To determine whether this is generally true would require research on the differentiation of a variety of response properties by negative reinforcement involving a variety of forms of aversive stimuli.

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